Reduction of Postharvest Decay of Peaches and Nectarines With Heat Treatments

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Introduction

In the United States and in several other countries experiments have been conducted for many years to reduce decay of peaches from the time they are picked until they are consumed. Most of this decay is caused by *Monilinia fructicola* (Wint.) Honey (the brown rot organism) or *Rhizopus stolonifer* (Fr.) Lind. A recent survey showed that in one major city in the United States 3 percent of the peaches shipped were either destroyed during transit or during unloading and an additional 6 percent were lost during retail handling (*14*).[1] Much of these losses was due to decay. Though the losses may not appear to be great, they represent means of many observations. Losses as great as 69 percent occurred in some shipments during transit. No records are available on what percent of this fruit decays from the time it leaves the retail store until it is consumed, but losses during this period are considered to be severe.

Most decay control operations include removing field heat from the peaches as quickly as possible followed by holding or shipping the fruit at low temperatures. Hydrocooling the fruit immediately after harvest is an extremely effective way of removing field heat. However, neither hydrocooling nor short transit periods at low temperatures reduce decay of peaches during the subsequent ripening period at more moderate temperatures. It is during this period that chemicals may be useful to reduce decay.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 23.

The chemicals approved for use on peaches by the Food and Drug Administration will reduce the spore load of the decay-producing organisms on the surface of the fruit, but will not prevent decay development once the organism has penetrated the fruit. One report showed that hot water treatments of peaches effectively reduce both the spore load on the surface and the decay-producing organism in the fruit (*11*). Other workers also have shown that hot water or hot air treatments effectively reduce decay of peaches and other fruits or vegetables (*1*, *2*, *4*, *5*, *8*, *9*. *10*, *13*).

Prepackaging of peaches in consumer-size units has been increasing in all parts of the country. Because of the acceptance of these units by consumer, retailer, and wholesaler, the volume is likely to continue to increase (*6*, *7*, *12*). Control of decay in prepackaged peaches is particularly important as the presence of a single decayed fruit in the package necessitates either repackaging, or sale at discount. In view of the increasing volume of prepackaged peaches, the packaging effect on any decay control measure should be investigated.

The present report expands some of these studies. Information is given on (a) effect of water temperature and length of exposure on decay development; (b) effect of holding at 50° or 32° F. and of hydrocooling on heated peaches; (c) peach temperatures during heating and hydrocooling; (d) decay of peaches at 70° F. as affected by hot water or hot air treatments; (e) effect of hot water on decay-producing organisms; (f) the effect of hot water on decay of peaches and nectarines packaged in open and overwrapped consumer-size units.

General Methods and Materials

Peaches were obtained from wholesale houses in Washington, D.C., or nearby orchards. Usually they were picked about 24 hours before use, and had a short transit or holding period at low temperatures. Test fruit were sorted for uniform size and maturity; they were free from decay, bruises, and other blemishes. They ranged from 1½ to 2½ inches in diameter. Firmness was about 10 to 12 pounds (Magness-Taylor Pressure Tester with a 5/16-inch tip.)

Fruit was inoculated by dipping it in a suspension of spores in beef-peptone broth containing 0.1 percent polyoxyethylene sorbitan monolaurate. Uninjured fruit was inoculated with spores of the brown rot organism (*M. fructicola*); a shallow cut, resembling a fingernail injury, was made on each cheek of fruit inoculated with *R. stolonifer* spores. The suspension contained 20 to 30 *Monilinia* or 70 to 80 *Rhizopus* spores per low power field of a microscope.

Most of the data from these tests were subjected to an analysis of variance and significant differences at the 1 percent level between means determined by the Duncan Multiple Range test.

Part I

Factors Involved in Effective Heat Treatment of Peaches

Summary

Peaches inoculated with *Monilinia fructicola* (the brown rot organism) or *Rhizopus stolonifer* spores an hour before treating in 120° or 130° F. water consistently developed far less decay at 70° than those treated with room temperature (75°) water.

Treatment of peaches for 1½ minutes in 130° F. water or 3½ minutes in 120° water reduced both Monilinia and Rhizopus decay in peaches held 4 days at 70° about as well as treatment at these temperatures for 3 or 7 minutes, respectively. Exposure for 3 minutes to 130° water sometimes caused a tan skin mottling.

Peaches treated in 130° F. water, then held at 32° or 50° F. developed less decay after transfer to 70° than comparable heat-treated peaches hydrocooled in 34° water and held at 50° before transfer to 70°. Hydrocooling has the advantage, however, of being a rapid method of cooling peaches.

Treatment of peaches in 130° F. air with 70 percent relative humidity for 20 minutes or 80 percent relative humidity for 15 minutes controlled decay about as well as heating in 130° water. When the relative humidity of the 130° air was 50 or 60 percent, decay was not effectively controlled.

Most of the *Monilinia* and *Rhizopus* spores on the surface and vegetative growth of these organisms under the peach skin were killed when fruit was submerged in 130° F. water for 3 minutes.

During 3-minute exposures to 130° F. water, flesh temperatures of peaches increased about 30 degrees under the skin and 10 degrees near the pit. During heating in 130° air, flesh temperatures increased more and faster if the relative humidity of the air was high (80 to 90 percent) than if it was low (50 percent).

Effect of Water Temperature and Length of Exposure on Decay Development

To determine the effect of length of exposure in hot water on subsequent decay at 70° F., peaches inoculated with *Monilinia* or *Rhizopus* spores were placed in large wire containers (bulk lots) and submerged for 3½ or 7 minutes in 120° or 1½ or 3 minutes in 130° water. Cumulative decay of these fruit after 4 and 6 days at 70° was compared with decay of peaches dipped in 75° water (wet checks) and those not dipped (dry checks).

During the 4 or 6 days at 70° F. all peaches treated with hot water developed considerably less decay than either of the unheated checks (table 1). All of the treatments involving 120° or 130° water were about equally effective in reducing the Monilinia decay in peaches held at 70° for 4 days. However, those held for 6 days following treatment at 120° for 7 minutes had decidedly less decay than those treated for only 3½ minutes. Exposure times had little effect on Rhizopus decay when peaches were treated in 120° or in 130° water.

TABLE 1.—*Decay of peaches after 4 or 6 days at 70° F. as affected by water temperature and exposure time* [1]

Water temperature (°F.) and exposure time	Monilinia decay [2]		Rhizopus decay [2]	
	4 days	6 days	4 days	6 days
	Percent	*Percent*	*Percent*	*Percent*
120—7 minutes	2. 5 a	8. 8 a	13. 1 a	18. 1 a
120—3½ minutes	8. 8 a	30. 4 b	32. 7 a	39. 4 a
130—3 minutes	5. 6 a	12. 9 a	26. 3 a	39. 4 a
130—1½ minutes	7. 7 a	17. 3 ab	23. 0 a	35. 8 a
Dry check	49. 0 b	80. 4 c	83. 8 b	84. 4 b
Wet check	55. 6 b	77. 5 c	94. 2 b	94. 2 b

[1] Means followed by the same letter in individual columns are not significantly different at the 1 percent level.
[2] Means of 8 tests of 20 peaches each. Fruit were inoculated with *Monilinia* or *Rhizopus* spores.

These peaches usually were soft ripe after 2 or 4 days at 70° F. and overripe in 6 days. No difference in ripening was noted in the hot water treatments or the checks.

Effect of Holding at 50° or 32° F. and of Hydrocooling on Heated Peaches

To simulate conditions which may occur in commercial operations, 15 to 20 freshly inoculated peaches were mixed with 60 to 70 uninoculated peaches packed in new ½-bushel baskets with liners, and then the baskets were lidded. The baskets of fruit were submerged for 1½ or 3 minutes in a deep tank of water held at 130° F. As soon as possible after heating, some baskets were placed in a room at 50° with relative humidity about 90 percent. Other baskets, after removal of the lids, were hydrocooled in an ice-refrigerated flood-type hydrocooler until fruit temperatures at the pit averaged about 65°. The baskets of fruit were then allowed to drain for 5 minutes before being placed at 50°. Similarly prepared baskets of peaches were hydrocooled without heating and then placed at 50° (checks). All fruit remained at 50° for 2 days and then were transferred to 70° for ripening.

Two days after removal to 70° the peaches usually were soft ripe. The treatments did not affect ripening or flavor of the fruit, but sometimes the red or yellow skin color was intensified by the heat treatments. Six percent of the peaches in the hydrocooled checks had Monilinia and 19 percent had Rhizopus decay. The hot water treatments reduced Monilinia decay to less than 1 percent and Rhizopus decay to about 2 percent.

After 4 days at 70° F., decay in peaches caused specifically by *Monilinia* or *Rhizopus* was usually significantly lower in the heat-treated peaches than in the checks (table 2). Decay of peaches hydrocooled or those air cooled at 50° after heating did not differ significantly. Somewhat different results were obtained when Monilinia and Rhizopus decay were combined (total decay). Only the peaches air cooled at 50° had consistently less total decay than the checks. Peaches hydrocooled after heating therefore were more subject to contamination than air-cooled peaches. Contamination by *Rhizopus* apparently was more severe than by *Monilinia*.

Table 2.—*Decay of peaches after 4 days at 70° F. as affected by hydrocooling or holding at 50° immediately after treating with 130° water* [1]

Treatments	*Monilinia*-inoculated [2]		*Rhizopus*-inoculated [3]	
	Monilinia decay	Total decay	Rhizopus decay	Total decay
	Percent	*Percent*	*Percent*	*Percent*
130° F. water—3 minutes:				
Held at 50° (air cooled)	8. 7 a	15. 6 a	26. 7 a	33. 4 a
Hydrocooled, then held at 50°	9. 5 a	45. 6 ab	36. 8 a	46. 2 ab
130° F. water—1½ minutes:				
Hydrocooled then held at 50°	14. 3 a	23. 5 a	48. 6 ab	53. 3 ab
Hydrocooled only, then held at at 50° (check)	34. 3 b	58. 7 b	61. 3 b	66. 7 b

[1] Means in individual columns followed by same letter are not significantly different at 1 percent level.

[2] 15 to 20 fruit in each basket inoculated with *Monilinia* spores. Percent decay based on decay of inoculated and uninoculated fruit.

[3] 15 to 20 fruit in each basket inoculated with *Rhizopus* spores. Percent decay based on decay of inoculated and uninoculated fruit.

Peaches were also heated in the baskets in 120° F. water for 3 or 7 minutes before hydrocooling or air cooling at 50°. Decay of these peaches after transfer to 70° did not differ significantly from those heated in 130° water. Decay of all heated lots was significantly less than that of the unheated checks after 2 days at 70°, when the fruit was soft ripe. Only the air-cooled peaches had significantly less decay than the checks after 4 days at 70°.

Additional tests indicated that peaches held at 32° F. for 5 days immediately after heating in 130° water developed considerably less decay than the unheated (check) peaches during 2, 4, and sometimes 6 days at 70° (table 3). Rhizopus decay was reduced more by the combination heat and cold treatment than was Monilinia decay.

Table 3.—*Total decay of peaches at 70° as affected by holding 5 days at 32° F. immediately after treating with 130° water* [1]

Water temperature and exposure time	*Monilinia*-inoculated, held at 70° F.			*Rhizopus*-inoculated, held at 70° F.		
	2 days	4 days	6 days	2 days	4 days	6 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
75°—3 minutes (checks)	8. 9	50. 2	78. 3	17. 3	63. 5	78. 0
130°—3 minutes	2. 3	20. 4	54. 3	. 5	10. 9	36. 0
130°—1½ minutes	1. 7	20. 7	45. 3	1. 0	10. 0	27. 0

[1] Mean of 2 tests with ½-bushel basket of peaches. All peaches held 5 days at 32° F. after heat treatment before transfer to 70°.

Peach Temperatures During Heating and Hydrocooling

Peach temperatures were taken about one-eighth inch under the skin, and near the pit, with 30-gage wire thermocouples attached to a direct reading potentiometer. The skin puncture made by the thermocouples was sealed with a sealing wax compound. Fruit temperatures were taken in the bottom, middle, and top positions of the baskets. A delay of about 2 minutes occurred from the time peaches were removed from the hot water baths until they were hydrocooled. After hydrocooling the baskets were allowed to drain for 5 minutes before they were placed at 50° F.

During the 130° F. water treatment the temperatures of the peaches in all three positions in the baskets increased at about the same rate. All fruit, regardless of the starting temperature, reached about the same temperature one-eighth inch below the skin by the end of the 3-minute exposure to 130° water (fig. 1). In all cases there was a very rapid increase in temperature during the first minute and a slow increase thereafter. Final temperatures near the pit were much lower and were governed by the starting temperature of the fruit. About one-half of the increase occurred during the first minute of exposure. Peaches heated 1½ minutes in 130° water had about the same temperature under the skin as those heated for 3 minutes, but the temperatures near the pit were lower.

When peaches were heated in 120° F. water, the temperature rise under the skin also was extremely rapid and that near the pit gradual. After exposure for 7 minutes, temperatures under the skin were slightly lower, but those near the pit higher than temperatures of peaches exposed 3 minutes in 130° water.

While the peaches were being transferred from the heating tank to the hydrocooler, temperatures under the skin dropped about 10 degrees and pit temperatures increased slightly. During the first minute of hydrocooling, the temperature one-eighth inch below the skin decreased very rapidly, and then at a nearly constant but much slower rate (fig. 2). Pit temperatures decreased slowly at an almost uniform rate, the time necessary to reach about 65° F. being deter-

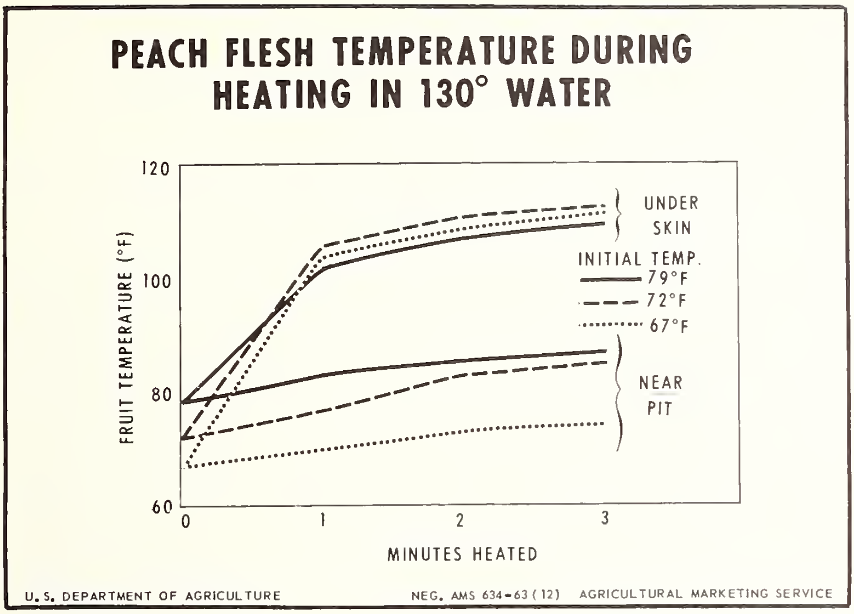

FIGURE 1

mined by the temperature near the pit at the start. Hence, the peaches heated 7 minutes in 120° water took longer to cool to 65° than those heated 3 minutes in 130° water. Peaches with short exposure to hot water (3½ minutes at 120°, 1½ minutes at 130°) cooled more

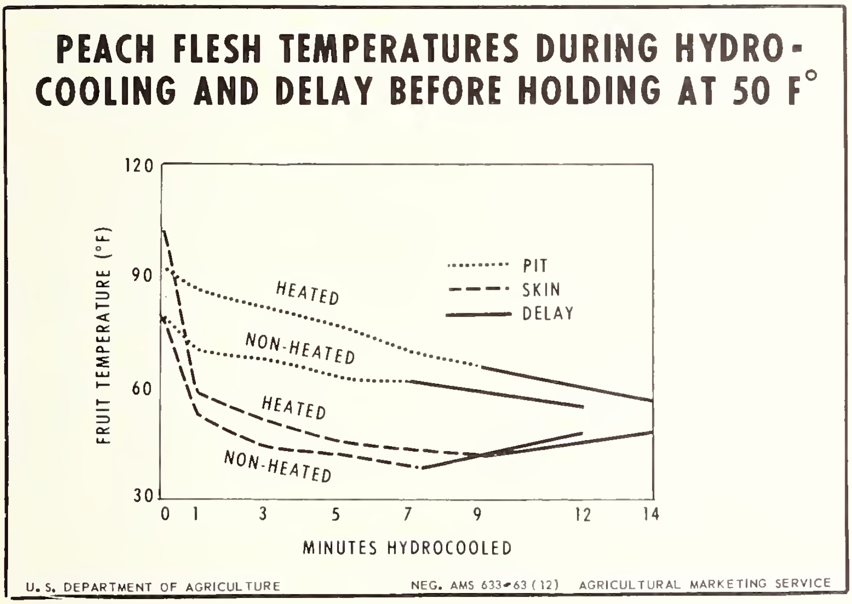

FIGURE 2

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rapidly than those with long exposures. Usually the cooling rates for the heat-treated peaches were about the same as those of the unheated peaches, but it required about 2 to 3 minutes longer exposure to the 34° water for the heat-treated peaches to reach the same temperature as the unheated fruit.

During the 5-minute delay between hydrocooling and placement at 50° the temperature under the skin rose about 5 degrees while the temperature near the pit continued to drop.

Decay of Peaches at 70° F. as Affected by Hot Water or Hot Air Treatments

Lots of 20 peaches each were treated with hot water in the manner previously described. For the hot air treatments, bulk lots of fruit were placed in containers in an enclosed chamber with 130° F. air circulated by a 1/6-hp. blower motor. Relative humidity was determined by the difference in wet and dry bulb temperatures.

After 4 days at 70° F., there usually was no significant difference in the percent decay that developed in *Monilinia*- or *Rhizopus*-inoculated peaches treated with hot water or hot air (table 4). All treatments except 130° air at 95 and 50 percent relative humidity resulted in significantly less Monilinia decay than the wet checks. Only the peaches heated in 130° air at 80 percent relative humidity and those heated in 130° water and in 120° water for 7 minutes had significantly less Monilinia decay than the dry checks. All of the treatments except 130° air at 50 percent relative humidity reduced Rhizopus decay far below that of either check.

TABLE 4.—*Decay of peaches at 70° F. as affected by hot water or hot air treatments* [1]

Treatment	Monilinia decay after—		Rhizopus decay after—	
	4 days	6 days	4 days	6 days
	Percent	*Percent*	*Percent*	*Percent*
120° F. water:				
7 minutes	4 a	14 a	15 a	19 a
3½ minutes	14 ab	35 ab	42 ab	44 ab
130° F. water:				
3 minutes	8 a	12 a	31 ab	40 ab
1½ minutes	4 a	11 a	37 ab	51 ab
130° F. air:				
50% RH—20 minutes	32 abc	82 d	66 bc	69 bc
60% RH—20 minutes	22 ab	56 bcd	43 ab	51 ab
70% RH—20 minutes	18 ab	38 ab	21 a	21 a
80% RH—15 minutes	9 a	34 ab	17 a	29 ab
90% RH—10 minutes	20 ab	56 bcd	39 ab	51 ab
95% RH—10 minutes	24 abc	48 bc	35 ab	50 ab
75° water–7 minutes, (wet checks)	52 c	75 cd	97 c	97 c
None (dry checks)	44 bc	77 d	98 c	98 c

[1] Means of 5 tests. 20 peaches in each test inoculated with *Monilinia* or *Rhizopus* spores. Means in individual columns followed by the same letter are not significantly different at the 1 percent level.

After 6 days at 70° F. reductions of Monilinia decay by 130° air at 70 and 80 percent relative humidity were about the same as those obtained with hot water. Only these two hot air treatments and the hot water treatments reduced this decay significantly below that of the checks. Rhizopus decay was significantly less in the treated peaches than in the checks in all treatments except hot air at 50 percent relative humidity.

Temperatures of peaches during the hot air treatments were measured in the same manner as during the hot water treatments. At relative humidities of 80 percent or higher the temperatures one-eighth inch below the skin and near the pit increased much more rapidly than at relative humidities below 80 percent (table 5). In these tests the longer exposures were not used at the higher relative humidities, because of the high fruit temperatures and possibility of injury.

TABLE 5.—*Peach flesh temperature changes as affected by the relative humidity of 130° F. air*

Area tested and exposure times (minutes)	Temperatures after exposure at relative humidities of—					
	50%	60%	70%	80%	90%	95%
	° F.	° F.	° F.	° F.	° F.	° F.
Under skin:[1]						
5	90	93	97	102	103	107
10	96	101	103	110	111	114
15	99	103	108	115		
20	102	105	111			
Near pit:						
5	78	80	82	86	87	87
10	84	87	90	92	95	95
15	84	93	96	102		
20	92	97	101			

[1] ⅛ inch below skin.

Effect of Hot Water Treatment on Decay-Producing Organisms

To determine the effect of hot water on the organisms producing decay of peaches, fruit with *Monilinia* or *Rhizopus* sporulating on its surface was submerged for 3 minutes in 130° F. water. Two types of infected fruit were used: (a) those with a light spore mass scattered over the surface, (b) those with the entire outer surface covered with dense spore masses. After heating, spores from the fruit were streaked on potato dextrose agar in petri plates and the plates incubated 1 day at 70°. Germination of these spores was compared with that of spores from fruit dipped in 75° water (checks).

The percent germination of *Monilinia* or *Rhizopus* spores from peaches heated in 130° F. water was decidedly less than the germination of spores from the check peaches (table 6). The density of the spore masses had no effect on percent germination of heated *Monilinia* spores, but more heated *Rhizopus* spores germinated when the spore masses were dense than when they were light.

TABLE 6.—*Percent germination of spores treated on the peach surface in water and then streaked on potato dextrose agar and incubated 24 hours at 70° F.*

Treating water temperature (°F.)	*Monilinia* spores		*Rhizopus* spores	
	Light spore mass [1]	Dense spore mass [2]	Light spore mass [3]	Dense spore mass [4]
	Percent	*Percent*	*Percent*	*Percent*
75	76. 6	90. 0	92. 7	80. 6
130	3. 3	1. 6	3. 4	36. 2

[1] Average of 6 tests, about 400 spores each test.
[2] Average of 9 tests, about 400 spores each test.
[3] Average of 9 tests, about 400 spores each test.
[4] Average of 8 tests, about 400 spores each test.

Peaches with decay symptoms extending from the skin to the pit also were submerged in 75° F (unheated checks) or 130° water for 3 minutes. Sections of decayed skin and decayed tissue at different depths in the flesh were placed on potato dextrose agar at 70° and the growth from the sections compared.

Characteristic growth developed from a high or very high percent of the sections from unheated Monilinia or Rhizopus decayed fruit within 2 days at 70° F. (table 7). In contrast, when decayed fruit were heated in 130° water, no growth occurred from skin sections of Monilinia decayed fruit and very few of the skin sections of Rhizopus decayed fruit produced growth. Growth did occur from some of the flesh sections of both types of heated fruit, but the number of sections which had growth were far fewer than the number of sections from similar areas in unheated peaches.

TABLE 7.—*Percent of sections from heated and nonheated decayed peaches producing growth on potato dextrose agar at 70° F.*

Treating water temperature (°F.) and location of decay	Monilinia decayed fruit [1]	Rhizopus decayed fruit [2]
	Percent	*Percent*
75:		
Skin	66. 7	95. 6
⅛ inch under skin	72. 7	93. 4
½ inch in flesh	47. 7	86. 8
130:		
Skin	0	4. 4
⅛ inch under skin	25. 0	10. 5
½ inch in flesh	25. 0	61. 8

[1] Average of 11 fruit, 4 isolates from each location of each fruit.
[2] Average of 19 fruit, 4 isolates from each location of each fruit.

These data show that both *Monilinia* and *Rhizopus* spores and vegetative growth are extremely sensitive to short exposures to water at 130° F. The data do not agree with the thermal death times reported for the two organisms (*3*). They do, however, help to explain the reduction of Monilinia and Rhizopus decay of peaches by heat treatments in these and previously reported tests (*11*).

Discussion

Short exposures to 120° or 130° F. water were lethal to most of the spores of *Monilinia fructicola* and *Rhizopus stolonifer* on the surface of peaches and to some of the vegetative growth of these organisms in the flesh of the peach. The heat treatments were slightly more harmful to *Monilinia* spores than to those of *Rhizopus*. Although a low percentage of the spores survived the hot water treatments, these spores may have been partially responsible for the decay of bruised, overripe peaches during the long holding periods in these tests. Though these treatments destroyed a high percentage of the vegetative growth of the organisms on the skin and in the flesh just below the skin, the organisms survived when they had penetrated one-eighth inch or more into the flesh. The hot water treatments therefore may destroy a large percentage of the organisms in or on the fruit but do not necessarily eradicate them, particularly if the organisms have penetrated into the flesh.

The almost equal effectiveness of several periods of submersion in hot water in reducing decay indicate that the duration of submersion has some degree of flexibility. Temperature rise just under the skin in either 120° or 130° F. water was extremely rapid and apparently was high enough after very short exposures to reduce the population of the organisms causing decay. Both periods of submersion in water at 120° or 130° F. almost eliminated decay for 2 days at 70° when the peaches were soft ripe and greatly reduced decay below that of the checks during the additional 4-day holding. A tan-colored skin mottling sometimes occurred on peaches heated in 130° water. Submersion of peaches for longer than 3 minutes in water at that temperature therefore is apt to cause serious injury.

The studies with hydrocooling and air cooling after the hot water treatment simulate conditions which may occur commercially. The peaches inoculated shortly before the heat treatments represent those which may be inoculated with *Monilinia* or *Rhizopus* spores during packinghouse operations. Such peaches often decay in containers, and are responsible for spread of decay throughout the containers. The hot water treatments apparently prevented most of the decay of these peaches.

The simulated transit periods at 50° F. or holding periods at 32°, show that hot water treated peaches theoretically have at least 2 and often 4 subsequent days at 70° for wholesale and retail marketing without danger of serious decay. The studies indicate that it is better to air cool than to hydrocool the peaches after the hot water treatments. Even the hydrocooled fruit was almost free of decay after 2 days at 70°. At that time the fruit was soft ripe and hence easily bruised and subject to infection by *Rhizopus*, the chief contaminant in these tests. Undoubtedly, chance of contamination would be more apt to occur in hydrocooled than in air-cooled fruit, but careful packinghouse sanitation could reduce such contamination. Since hydrocooling is a very rapid method of cooling, it may still be the most practical method of cooling in packinghouses equipped with a hydrocooler.

Two methods of treating the peaches in hot water are described, (a) the simulated bulk method where peaches were treated in large wire containers and (b) treating fruit packed in ½-bushel baskets. Both methods raised fruit temperatures and reduced decay about the same. The uniformity of heating of fruit in the packed basket indicates this method of treatment, as well as the bulk method, may have commercial possibilities. In these studies, packed and lidded baskets were held under water by iron grating and the baskets pushed through the hot water bath at the desired rate, and then hydrocooled. Because peaches float in water, a similar pusher could be used to move bulk peaches continuously through the bath. Either type of treatment may fit into the packing line of a peach packing shed. Steam was used to heat the water in these studies and also could be used commercially, but other methods may be even more desirable.

These studies also show the importance of relative humidity if peaches are treated by short exposures to hot air. With air at low relative humidity (50 percent), fruit temperatures increased slowly and apparently not enough to affect the organisms. At the higher relative humidities (90 and 95 percent) fruit temperatures increased rapidly. These extremely high relative humidities were difficult to obtain in short periods even with the small lots of fruit used. On the other hand, 70 and 80 percent relative humidities were relatively easy to obtain and since 130° air for 15 or 20 minutes at these relative humidities gave excellent decay reductions such relative humidities show promise for further testing.

Part II

Packaging Tests

Summary

Treating peaches inoculated with *Monilinia* or *Rhizopus* spores by immersion in hot water (130° F.) for 3 minutes before packaging in consumer units markedly reduced spoilage.

The type of package generally had no effect on the percentage of peaches that decayed during storage.

Weight losses from peaches were greatest in open trays, and greater in cellophane-overwrapped than in polyethylene-overwrapped trays.

Trays filled with peaches previously inoculated with either *Monilinia* or *Rhizopus* spores and treated with tap water were not salable following simulated transit and marketing periods because of the high percentage of decayed fruit. When treated with hot water before packaging, most of the units remained salable during the test. Salability was highest when the trays were overwrapped with perforated cellophane. Weight losses in open trays and excessive condensation within polyethylene overwrapped trays were disadvantages of these types of packages.

In general, results with nectarines were similar to those obtained with peaches.

Methods and Materials

After the peaches were inoculated as described under "General Methods and Materials," they were spread on a laboratory bench and allowed to dry for approximately 2 hours. One-half of the fruit in each test was then immersed in hot (130° F.) water for 3 minutes. The remaining half was immersed in tap (75° F.) water for the same period. All fruit was then replaced on the laboratory bench and dried.

Care was taken to prevent contamination of the peaches by covering the laboratory bench with clean kraft paper each time the fruit was spread to dry. In addition, the workers' hands were thoroughly washed before handling the fruit from each of the different treatments.

After drying, the peaches were placed in shallow pulp trays holding six peaches. One-third of the total number of trays were left unwrapped; one-third were overwrapped with perforated 1- or 1.2-mil polyethylene film; and one-third were overwrapped with perforated or unperforated, non-moistureproof cellophane. The 16″ by 17″ polyethylene overwraps were perforated with twenty ⅛-inch holes.

The cellophane overwraps were of the same size and, when perforated, also contained twenty ⅛-inch holes. Unperforated cellophane overwraps were used in two tests and perforated overwraps were used in four tests.

After overwrapping, all packages were weighed. One-half of the packages containing peaches dipped in hot water, and one-half of those containing peaches dipped in tap water, were held at 50° F.; the remainder were held at 70°. The 50° holding was used to simulate a transit temperature, while 70° holding represented the temperature during marketing. Each type of package was replicated five times at each holding temperature.

Peaches inoculated with *Monilinia* spores were inspected after 4 days at 70° F., or after 4 days at 50° followed by 4 days at 70°. Peaches inoculated with *Rhizopus* spores were inspected after 2 days at 70°, or after 4 days at 50° followed by 2 days at 70°. At each inspection the packages were reweighed and rated for salability before the overwraps were removed. The number of decayed peaches and the type of decay in each package were then determined. Peaches selected at random from each of the three types of package were also rated for flavor.

Three varieties of peaches were used in the Monilinia (brown rot) tests, namely, Sun High, Brilliant, and J. H. Hale. Cloverleaf, a strain resembling J. H. Hale, was used in two Rhizopus tests and J. H. Hale was used in the third.

Carbon dioxide and oxygen concentrations within unperforated cellophane and perforated polyethylene overwraps were determined in two tests with an Orsat-type gas analyzer. Relative humidity within the overwraps was measured with an electric hygrometer in one test.

Two tests were conducted, using LeGrand nectarines. The methods of inoculation, packaging, and inspection were similar to those used in the peach tests. The number of inspections was reduced, however. *Monilinia*-inoculated nectarines were inspected only after 4 days at 50° F. followed by 4 days at 70°, and *Rhizopus*-inoculated nectarines after 4 days at 50° followed by 2 days at 70°.

Peaches

Effect of Water Treatment and Storage on Decay

Monilinia-inoculated.—Almost 88 percent of the peaches immersed in tap water (75° F.) decayed during the simulated transit and marketing periods. When immersed in hot water (130° F.), only 13 percent decayed (table 8). Over 98 percent of the decay was brown rot. Decay in peaches that had been immersed in tap water also was much further advanced than that in peaches immersed in hot water.

Although growth of the brown rot organism is retarded, it is not prevented at low temperatures. Peaches held 4 days at 50° F. decayed in greater number after being placed at 70° than peaches that were placed directly at the higher temperature following water treatment (table 8). The difference was most pronounced with peaches treated with tap water in open trays where over 30 percent more fruit decayed when the 4-day holding period at 70° was preceded by 4 days' storage at 50°.

Generally, the type of package had no significant effects on the decay of peaches. However, when peaches treated with tap water were stored 4 days at 70° F., a smaller number decayed in open trays than in either of the overwrapped trays. This was probably due to the lower relative humidity (85 percent) in the open trays, compared with 90 percent in the cellophane and 95 percent in the polyethylene overwrapped trays.

TABLE 8.—*Peaches inoculated with* Monilinia *or* Rhizopus *spores: Effect of water treatment, storage, and packaging on decay*

Inoculum, storage time and temperature, and type of tray	Peaches decayed after treatment in water[1]	
	At 75° F.	At 130° F.
Monilinia spores		
4 days at 50° F. plus 4 days at 70°:	*Percent*	*Percent*
Open	96.3 a	17.7 b
Polyethylene overwrapped	95.3 a	22.2 b
Cellophane overwrapped	96.3 a	14.8 b
4 days at 70° F.:		
Open	65.7 b	5.5 c
Polyethylene overwrapped	88.8 a	13.8 c
Cellophane overwrapped	84.3 a	3.7 c
Average (all packages and storage times)	87.8 a	12.9 b
Rhizopus spores		
4 days at 50° F. plus 2 days at 70°:		
Open	78.7 a	19.5 b
Polyethylene overwrapped	94.5 a	21.3 b
Cellophane overwrapped	89.8 a	14.8 b
2 days at 70° F.:		
Open	85.2 a	13.8 b
Polyethylene overwrapped	91.7 a	13.8 b
Cellophane overwrapped	88.8 a	17.7 b
Average (all packages and storage times)	88.1 a	16.8 b

[1] Each figure, except the average, represents the percent decayed of 108 fruits. Means within any block followed by the same letter are not significantly different at the 1 percent level.

Rhizopus-inoculated.—As with *Monilinia*-inoculated fruit, *Rhizopus*-inoculated peaches developed far less decay if they were immersed in hot water (130° F.) for 3 minutes before storage than if they were immersed in tap water (75° F.) (table 8). During 2 days' holding at 70°, or 4 days at 50° followed by 2 days at 70°, about 17 percent of the peaches that were immersed in hot water decayed, compared with 88 percent when tap water was used. Over 99 percent of the decay appeared to be caused by *Rhizopus*.

The type of package had no influence on Rhizopus decay.

Effect of Packaging and Storage on Weight Losses

Weight losses were strikingly different in the three types of test packages. When held 4 days at 50° F. followed by 4 days at 70°, *Monilinia*-inoculated peaches lost an average of almost 6 percent of their original weight in open trays, slightly less than 4 percent in cellophane overwrapped trays, and less than 1 percent in polyethylene overwrapped trays (table 9). When the holding period was only 4 days at 70°, weight losses were less but in the same relative proportion. Temperature of the treatment water had no significant effect on weight losses.

TABLE 9.—*Peaches inoculated with* Monilinia *spores: Effect of packaging and storage on weight losses*

Type of tray	Weight losses [1]	
	After 4 days at 50° plus 4 days at 70°	After 4 days at 70°
	Percent	*Percent*
Open	5. 8 a	4. 3 b
Polyethylene overwrapped	. 7 e	. 4 e
Cellophane overwrapped	3. 7 c	2. 8 d

[1] Each figure represents the average loss in 24 trays, each containing six peaches. Means followed by the same letter are not significantly different at the 1 percent level.

Weight losses in *Rhizopus*-inoculated peaches were also greatest when stored in open trays, and greater in cellophane overwrapped than in polyethylene overwrapped trays, irrespective of the holding period or water treatment (table 10). As would be expected, slightly more moisture was lost in peaches held 4 days at 50° F. followed by 2 days at 70° than in peaches held only 2 days at 70°. Water temperature during treatment had no important effect on weight losses.

Effect of Water Treatment and Packaging on Appearance and Salability

Salability of almost all packages containing peaches treated with tap water after inoculation with *Monilinia* or *Rhizopus* spores was reduced to zero during storage because of severe decay (fig. 3). Minor decay of peaches treated with hot water reduced salability slightly. Condensation within polyethylene overwraps was often severe (fig. 4), reducing salability of peaches in them considerably. The 5 percent carbon dioxide and 8 percent oxygen in unperforated cellophane overwrapped trays apparently retarded ripening of the peaches and reduced their salability. Peaches ripened normally in perforated cellophane overwraps, and the excellent clarity of the film produced a highly salable display. Salability of peaches treated

Table 10.—*Peaches inoculated with* Rhizopus *spores: Effect of water treatment, storage, and packaging on weight losses*

Treatment water temperature (°F.) and type of tray	Weight losses [1]	
	After 4 days at 50° plus 2 days at 70°	After 2 days at 70°
	Percent	*Percent*
76°:		
Open	2.7 a	2.5 a
Polyethylene overwrapped	.4 f	.2 f
Cellophane overwrapped	1.8 c	1.2 e
130°:		
Open	2.3 b	2.1 b
Polyethylene overwrapped	.3 f	.1 f
Cellophane overwrapped	1.5 d	1.2 e

[1] Each figure represents the average loss in 36 trays, each containing six peaches. Means followed by the same letter are not significantly different at the 1 percent level.

with 130° F. water for 3 minutes was slightly reduced by a surface mottling which appeared on about 20 percent of the fruit (fig. 5). The mottling was apparent immediately after the peaches were removed from the hot water. Keeping quality apparently was not affected by this heat injury.

Peaches which did not decay ripened normally in either open trays or in those overwrapped with perforated films. Flavor after holding at 70° F. for 2 or 4 days, or at 50° for 4 days followed by 2 or 4

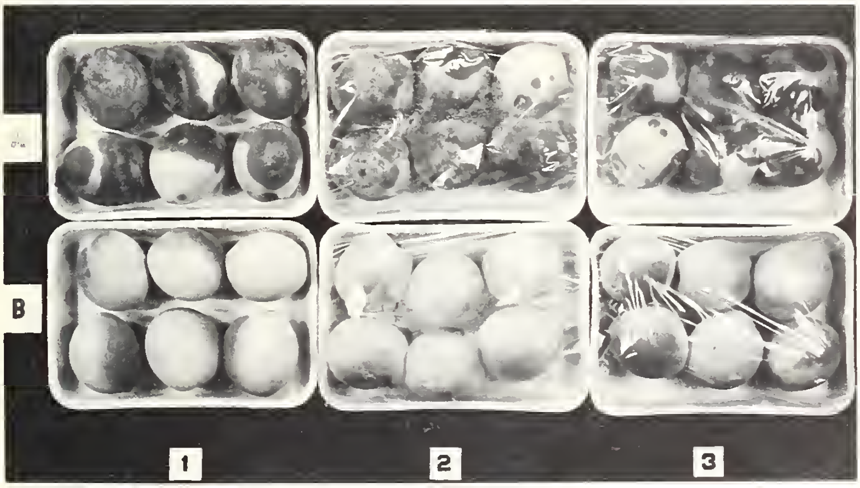

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FIGURE 3.—Peaches inoculated with *Monilinia* spores and immersed in (A) tap water, or (B) hot water, after 4 days at 50° F. followed by 4 days at 70°. (1) Open tray; (2) polyethylene overwrapped tray; and (3) cellophane overwrapped tray.

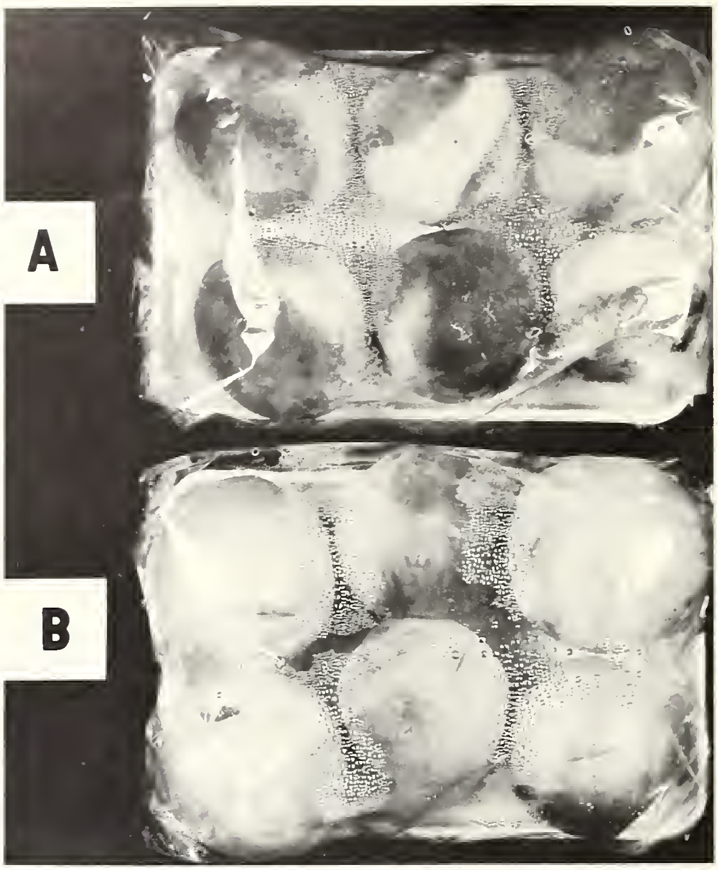

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FIGURE 4.—Peaches inoculated with *Rhizopus* spores and immersed in (A) tap water, or (B) hot water, after 4 days at 50° F. followed by 2 days at 70° in polyethylene overwrapped trays.

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FIGURE 5.—Mottling appearing on peaches immersed in 130° F. water for 3 minutes. (This injury appeared on about 20 percent of the treated fruit but, in most instances, was not this severe.)

days at 70°, was good to very good. Peaches in trays overwrapped with unperforated cellophane developed a fermented flavor while being held. This was apparently associated with the average concentrations of 5 percent carbon dioxide and 8 percent oxygen which were present within these overwrapped packages.

Nectarines

Effect of Water Treatment on Decay

Monilinia-inoculated.—Following treatment with tap water (75° F.) for 3 minutes, 81 percent of the *Monilinia*-inoculated nectarines decayed during storage at 50° for 4 days followed by 4 days at 70°. When treated with hot water (130° F.), 42 percent decayed (table 11). Approximately 85 percent of the decay was caused by the brown rot organism. Most of the remaining 15 percent was believed caused by *Diplodia*, particularly in fruit immersed in hot water.

TABLE 11.—*Nectarines inoculated with* Monilinia *or* Rhizopus *spores: Effect of water treatment, packaging, and storage on decay*

Inoculum, storage time and temperature, and type of tray	Nectarines decayed after treatment in water [1]	
	At 75° F.	At 130° F.
	Percent	*Percent*
Monilinia spores		
4 days at 50° F. plus 4 days at 70°:		
Open	66.7 ab	47.2 bc
Polyethylene overwrapped	90.3 a	50.0 bc
Cellophane overwrapped	87.5 a	30.6 c
Average (all packages)	81.5 a	42.6 b
Rhizopus spores		
4 days at 50° F. plus 2 days at 70°:		
Open	98.7 a	37.5 b
Polyethylene overwrapped	100.0 a	13.8 c
Cellophane overwrapped	100.0 a	8.3 c
Average (all packages)	99.6 a	19.9 b

[1] Each figure, except the average, represents the percent decayed of 72 fruits. Means within any block followed by the same letter are not significantly different at the 1 percent level.

Decay of nectarines treated with tap water appears to be considerably less in open trays than in the overwrapped trays. But because of the great variability between the individual trays, the difference was not statistically significant at the 1 percent level. For the same reason, decay of nectarines treated with hot water was not significantly different in cellophane overwrapped trays from that in open or polyethylene overwrapped trays.

Rhizopus-inoculated.—*Rhizopus*-inoculated nectarines treated with hot water kept significantly better than those treated with tap water (table 11). After 4 days at 50° F. followed by 2 days at 70°, nearly 100 percent of the fruit treated with tap water were decayed, almost entirely with rhizopus rot. Only 20 percent of the fruit treated with hot water decayed during the same period.

Nectarines treated with tap water decayed equally in all test packages. When treated with hot water, fewer fruit decayed in overwrapped trays than in open trays.

Effect of Packaging and Storage on Weight Losses

During storage for 4 days at 50° F. followed by 2 days at 70°, nectarines treated with hot water lost 1.5 percent of their original weight in open trays, 1.0 percent in cellophane overwrapped trays, but only 0.3 percent in polyethylene overwrapped trays. When the nectarines were held 2 additional days at 70° the losses were increased to 3.2 in open trays, 2.3 in cellophane overwrapped trays, and 0.7 percent in polyethylene overwrapped trays.

Weight losses in fruit treated with tap water could not accurately be determined because of the extensive decay present in most fruits.

Effect of Water Treatment and Packaging on Appearance and Salability

Decay reduced the salability of nectarines treated with tap water after inoculation with *Monilinia* or *Rhizopus* spores to almost zero in all packages.

When immersed in hot water before packaging, salability of the nectarines was highest following storage in trays overwrapped with perforated cellophane. The excellent clarity of the film and the absence of any substantial decay made this the most desirable package. Salability of nectarines in trays overwrapped with perforated polyethylene was reduced because of condensation of moisture on the interior of the overwraps. In open trays, some drying and a substantial amount of decay in the nectarines reduced salability. Nectarines which did not decay ripened normally in all packages.

Heat injury, which developed on some peaches as a surface mottling following immersion in hot water, was not observed on nectarines.

Discussion

The control of postharvest decay is particularly important in packaged peaches and nectarines where an entire unit may become unsalable because of a single decayed fruit. Complete control is often difficult because high humidity within enclosed packages is usually excellent for the growth of decay-producing organisms.

In the current tests, under conditions more conducive to decay than those usually found commercially, treating peaches or nectarines with 130° F. water markedly reduced decay caused by *Monilinia* and *Rhizopus*. Quality of the fruit was not affected by the hot water treatment except for a slight surface mottling on some of the peaches. In most instances, this mottling was not severe enough to affect the salability of the fruit.

The effectiveness of the hot water treatment was not influenced by the type of package in which the fruit was held even though relative humidities within cellophane and polyethylene overwraps were 5 to 10 percent higher than in open trays.

Peaches and nectarines in open trays lost considerably more weight during holding than fruit in overwrapped trays, indicating that some protective covering is desirable for packaged peaches and nectarines if the best quality is to be maintained during marketing. Any film that is used, however, should be sufficiently permeable to the passage of water vapor to prevent any fogging, which detracts considerably from the appearance of the package.

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